Report for 2002WY2B: Testing of hydrologic models for estimating streamflow in mountainous areas of Wyoming

- Conference Proceedings:
  - Ostresh, Lawrence M., James D. Riley, Hugh Lowham, and Bruce Brinkman, 2002. Gridding winter precipitation data in Wyoming mountains, poster session presented at Great Plains/Rocky Mountain Division of the Association of American Geographers, Missoula, MT, Oct. (presented by Ostresh), availability referenced in Volume 2, Supplemental Information Report.
  - Ostresh, Lawrence M., James D. Riley, Bruce Brinkman, and Hugh Lowham, 2003. Effect of land cover on winter streamflow in southeastern Wyoming mountains, poster session presented at the National Meetings of the Association of American Geographers, New Orleans, LA, March, (presented by Ostresh), availability referenced in Volume 2, Supplemental Information Report.
- Other Publications:
  - Brinkman, B.R. and H. Lowham. Winter flow modeling for the mountainous areas of Wyoming, in Wyoming Water Flow, Vol. LXIV, Issue 1, pgs 1-2.
  - Lowham, Hugh, Lawrence Ostresh, James Riley, Bruce Brinkman, and Justin Montgomery, 2003. Testing of hydrologic models for estimating low flows in mountainous areas of WyomingVolume 1, User Guide, Project Report, Available from Wyoming Water Development Commission, 6920 Yellowtail Road, Cheyenne, WY, 82002 or University of Wyoming, Water Resources Data System, Laramie, WY, 82071.
  - Lowham, Hugh, Lawrence Ostresh, James Riley, Bruce Brinkman, and Justin Montgomery, 2003. Testing of hydrologic models for estimating low flows in mountainous areas of WyomingVolume 2, Supplemental Information, Supplemental to Project Report, Available from Wyoming Water Development Commission, 6920 Yellowtail Road, Cheyenne, WY, 82002 or University of Wyoming, Water Resources Data System, Laramie, WY, 82071.
- Dissertations:
  - Riley, James D., 2003. Hydrologic modeling of winter streamflow in mountainous areas of southeast Wyoming, Master of Arts Thesis in Geography/Water Resources, Dept. of Geography and Recreation, A&S College, University of Wyoming, Laramie.

Report Follows:

Preface

The following report is taken from a draft of Volume 1 of the final report for this project. The project's final report was being revised when this annual report was submitted. Both volumes of the final project report are discussed in the Introduction section shown below and are listed in the publications section of this annual report. The final project report will be available from the Wyoming Water Resources Data System and the Wyoming Water Development Commission.

Abstract

Accurate estimates of streamflow are commonly needed for streams in mountainous areas. This report summarizes results of a study done of low flows for streams in the Medicine Bow Mountains and Sierra Madre of Wyoming. Streamflow-discharge measurements were made at a large number of sites during the low-flow winter months. These discharge measurements were correlated with data from nearby long-term streamflow stations. Refinements were made to equations for estimating winter (low) flows of small mountain streams. Mean monthly flows can be estimated by using the equations in this report, which use drainage area and range in basin elevation as independent variables.

Introduction

Projects involving streams often require flow data. The ideal situation during planning and design is to have at least 5 years of streamflow record available for the site. However, economic constraints commonly prevent gage installation and operation everywhere streamflow information may be needed. If no gaging station has operated at or near a study site, it may be necessary to estimate streamflows.

This report summarizes research results from testing and refining models for estimating low flows of small streams in the mountainous areas of southeast Wyoming. The Wyoming Water Development Commission (WWDC), the U.S. Geological Survey (USGS), and the University of Wyoming (UW) provided funding for the 3-year study, which began July 1, 2000. The final report is presented in two volumes. This report (*Volume 1, Users Guide*) provides a brief description of the study, presents the estimating equations, and gives an example for using the equations. Summaries of the planning and review meetings, descriptions of the field visits, and supplemental reports produced during the study are compiled in *Volume 2, Supplemental Information*.

Objectives

The objectives of the study were to:

- Test the accuracy of various techniques for estimating streamflows at ungaged sites in mountainous areas, especially during the low-flow period of winter,
- Investigate methods for improving the accuracy of estimating techniques, and
- Provide research and technical experience for a University of Wyoming student.

Approach

The study plan was coordinated with the Wyoming State Engineer's Office, U.S. Forest Service, and U.S. Geological Survey (USGS). Field visits and sharing of resources and data were coordinated with USGS. To minimize travel costs, a study area near Cheyenne and Laramie (home bases for the principal investigators and UW students) was chosen.

For the first year of the study, sites on the following drainages were selected for study and measurement:

- Brush Creek in the Medicine Bow Mountains, and
- Nash Fork Creek, tributary to Little Laramie River in the Medicine Bow Mountains

A review of data collected from these sites showed that additional drainages, with a greater diversity of basin characteristics, were needed to accomplish the study objectives. For the second year of the study, additional sites were selected in the following drainages:

- Encampment River in the Sierra Madre,
- Rock Creek and Little Laramie River in the Medicine Bow Mountains, and
- Douglas Creek in the Medicine Bow Mountains.

Figure 1 shows location of the drainage basins.

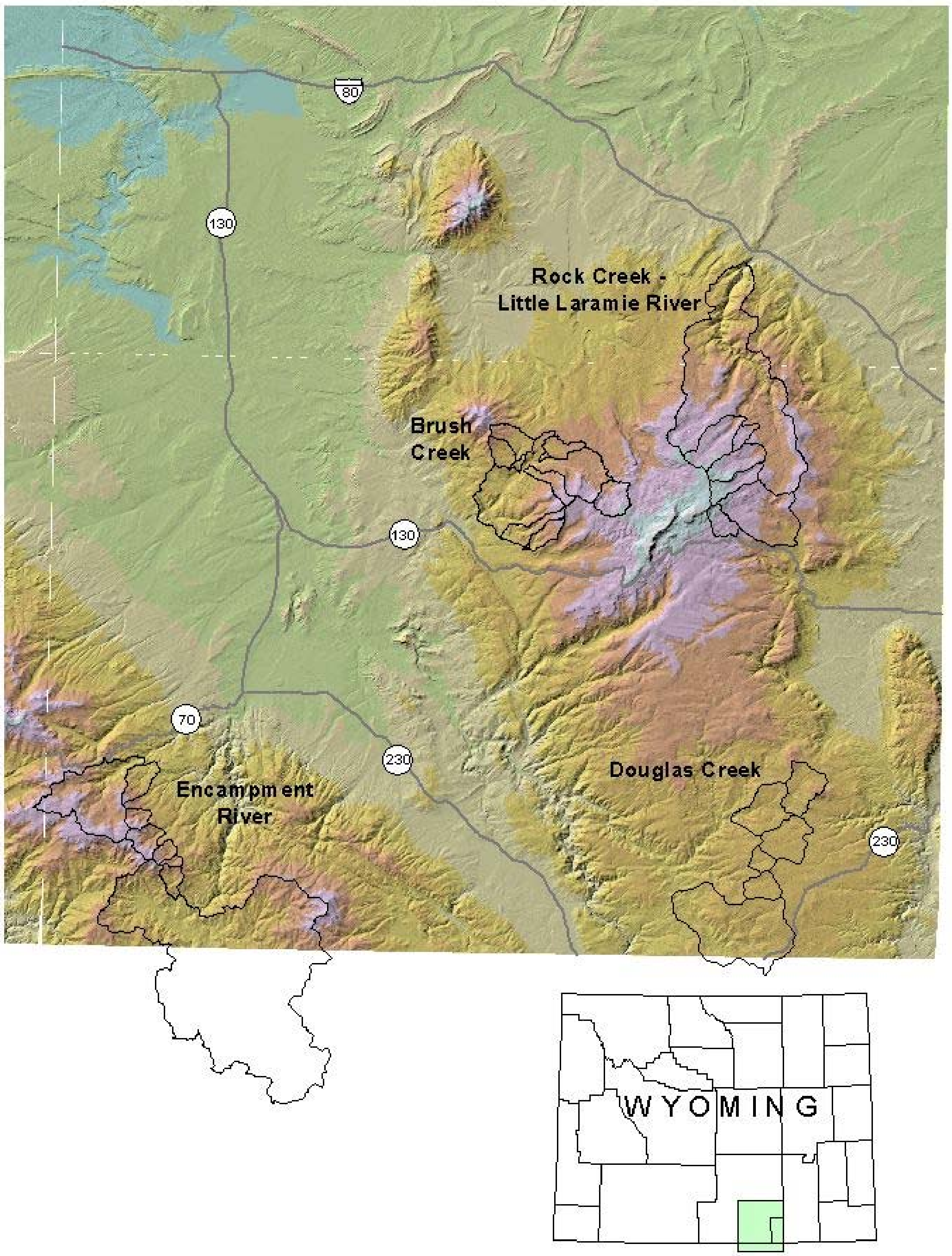

Figure 1. Location of the drainage basins selected for this study.

Previous Studies and Available Data

Previous studies for estimating flows of mountainous streams include Lowham (1988) and Misalis, Wesche, and Lowham (1999). These studies used streamflow data from gaged sites with essentially natural flows, measurements of basin characteristics from topographic maps, and measurements of channel dimensions from field observations. Drainage area, basin elevation, and mean annual precipitation are the basin characteristics generally found to be significant in determining the magnitude of annual and monthly runoff. This study included these same data, but also used monthly streamflow measurements on numerous small streams and basin characteristics that were newly identified by technology such as geographic information systems (GIS).

Available USGS streamflow-station data include:

- Daily values of streamflow
- Summaries of flow statistics, including mean annual and monthly flows, and maximum and minimum flows.

Available basin data include:

- Basin characteristics and channel measurements at streamflow stations;
- Digital files reflecting elevation, slope, aspect, primary vegetation, surface soils, bedrock and surface geology, and land ownership (primarily federal); and
- Snow and precipitation measurements collected at SNOTEL (SNOpack TELemetry) and snowcourse sites operated by the Natural Resources Conservation Service, and at weather stations operated by the National Weather Service

Streamflow Data Collection

Monthly measurements of streamflows were made at about mid-month from October through March or April at each of the selected sites (figs. 2-5) in the six drainage basins (Brush Creek and Little Laramie River during 2000-2001; Encampment River, Rock Creek, Little Laramie River, and Douglas Creek during 2001-2002). Streamflows at nearby gaged sites were measured concurrently.

Figures A-1 to A-6 (Appendix A) show locations of measurement sites and example maps developed through GIS technology for the Brush Creek area. Figures A-7 to A-10 (Appendix A) show locations of the measurement sites for the other study areas. Tables B-1 to B-3 (Appendix B) summarize locations and data for the sites.

Figure 2. Data collection on Haden Creek, site BC-9, July 15, 2002.

Figure 3. Measurement of channel width on unnamed tributary to Fish Creek, site BC-5, July 15, 2002.

Figure 4. Streamflow measurement using a bucket at a culvert on Middle Fork Rock Creek, site MB-4, February 12, 2002.

Figure 5. Streamflow measurement using a current meter on Harden Creek, site BC-9, January 16, 2001.

Initial visits were made to observe basin conditions at each site and to select measurement locations. Monthly measurements of discharge were made using standard procedures (Rantz, 1982). The sites were accessed during the winter using snowmobiles and snowshoes. A snow shovel and ice bar commonly were needed to clear the measurement section. Snow cover at the study sites can exceed depths of 5 feet (Brinkman and Lowham, 2001).

Volumetric measurements were made using a calibrated bucket and stopwatch at road crossings with culverts. Buckets of 6 to 12 gallons were used, with the size depending on the clearance between the streambed and the invert of the culvert. A current meter was used where suitable culvert sites were not available. Table B-2 summarizes the streamflow measurements.

Basin and Channel Characteristics

Basin characteristics, such as drainage area, basin elevation, and basin slope, were determined using digital maps for each sub-basin (see figures A-1 through A-10, Appendix A). Aerial photographs and/or imagery were examined to determine unique characteristics of the sub-basins that would have an influence on the magnitude of monthly runoff. For example, digital orthophotos revealed patterns of timber harvest and meadows.

The physical variables included contributing drainage area and perimeter; basin slope and basin elevation, including measures of mean, maximum, minimum, and range of elevation and slope; aspect; and areas of clearcut and wetland. Climatic variables measured for each basin included average annual precipitation and long-term average January through April snow-water equivalents. Field measurements of channel width were also obtained for each stream site.

Development of Estimating Equations

The selected basins were analyzed to determine features that could be used as parameters to develop estimating equations. The first step was to determine features of mountainous basins that could be identified and defined from existing data. Elevation, slope, aspect, vegetation type and percent of cover, and surface soil types are features that are relatively easy to identify using existing maps. The next step was to examine precipitation and geology maps and remote-sensing products to determine additional features that could be related to the magnitude of low flows.

For example, figure 6 is a graph that shows the relation of February mean flow to drainage area. The best-fit relation shows that discharge increases with drainage area. Some sites have relatively high yields, and thus plot above the best-fit line. Other sites have relatively low yields, and plot below the line. Parameters in addition to drainage area were subsequently investigated to determine why, for example, most of the streams in the North Brush Creek drainage would have relatively high yields, while many in the Douglas Creek drainage would have relatively low yields.

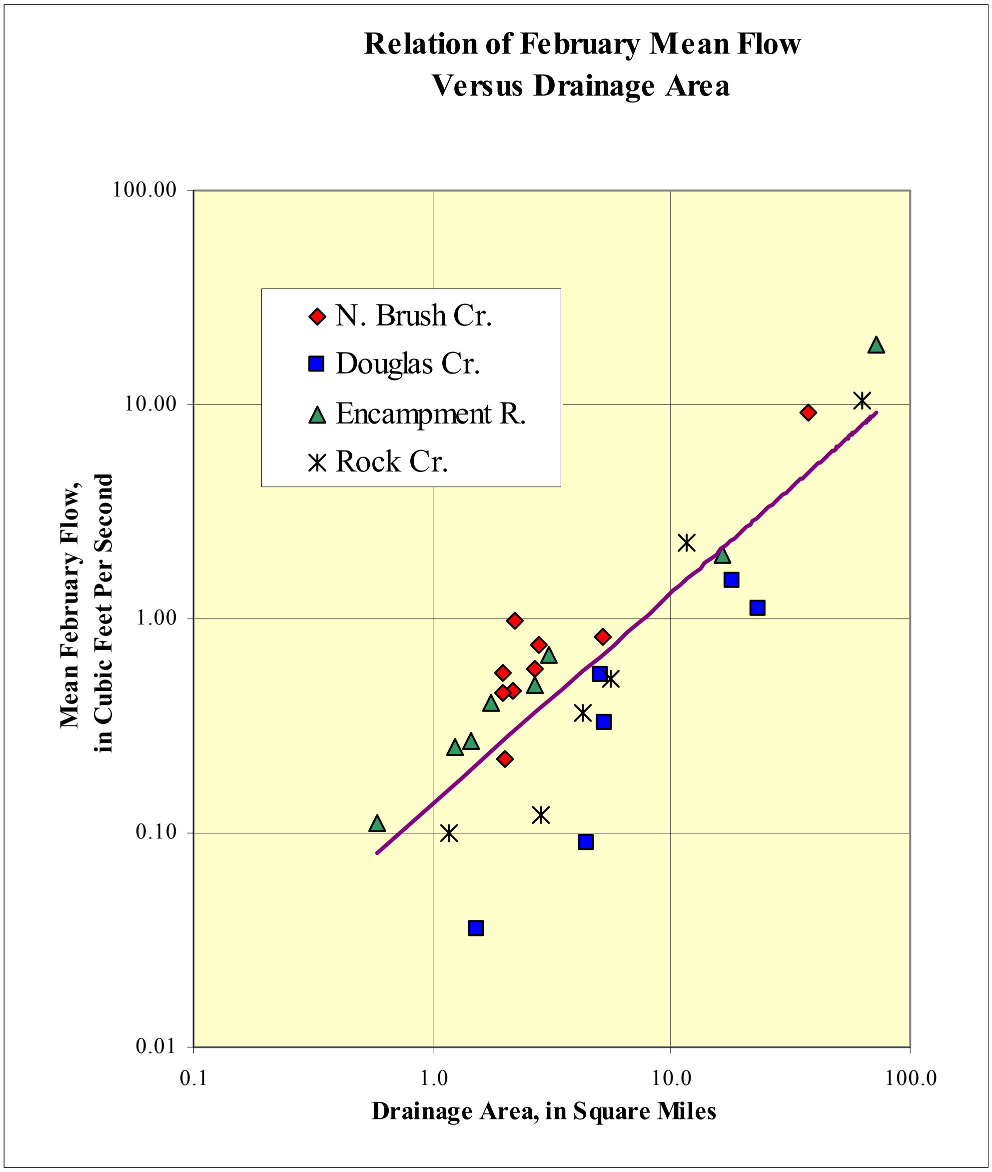

Figure 6. Graph showing relation of February mean flow to drainage area.

The streamflow data and basin characteristics were used to develop estimating equations through the use of multiple regression. The equations express flow characteristics (dependent variables) in relation to basin characteristics (independent variables). The data were transformed to logarithms before the regression analyses. Experience has shown that such transformation of hydrologic variables produces linear relations, which can be readily described by mathematical relations.

The following characteristics were determined as significant independent variables in the regression equations:

- **Contributing drainage area (Area)**, in square miles, measured from digital 1:24,000-scale topographic maps.
- **Range in elevation (Rng El)**, in feet, measured as difference in elevations from stream channel at lowest end of basin to highest point in basin divide.

Data for the significant variables are summarized in table B-1 (Appendix B).

Large areas of clearcuts and wetland meadows exist in the North Brush Creek drainage, but not for the combined study areas as a whole. Accurately depicting clearcuts in the regression equations is difficult because the areas change as timber harvest and new growth occur.

A precipitation measure, snow-water equivalent for April, was found to be slightly less significant than range in elevation. As part of the study, maps were developed for the Medicine Bow Mountains and Sierra Madre showing lines of equal value for April snow-water equivalent. These maps could be useful in a future study for determining estimates of high flows, provided that data at additional streamflow stations could be obtained.

Equations for estimating mean monthly flows for October through March are summarized below:

		Equation	R^2
Q_{Oct}	=	$0.000066\ Area^{0.80}\ RngEl^{1.14}$	0.84
Q_{Nov}	=	$0.000023\ Area^{0.61}\ RngEl^{1.32}$	0.87
Q_{Dec}	=	$0.000073\ Area^{0.67}\ RngEl^{1.11}$	0.80
Q_{Jan}	=	$0.000099\ Area^{0.68}\ RngEl^{1.06}$	0.73
Q_{Feb}	=	$0.000149\ Area^{0.71}\ RngEl^{1.00}$	0.80
Q_{Mar}	=	$0.000522\ Area^{0.79}\ RngEl^{0.82}$	0.81

where

Q_m	=	mean monthly flow, in cubic feet per second, with $_m$ designating the month;
Area	=	contributing drainage area, in square miles;
RngEl	=	range in elevation, in feet; and
R2	=	coefficient of determination.

The equations were developed using English units, and English units must be used unless applicable conversion factors are applied. The equations should be used for estimating low flows only within the ranges of data used for their development, which includes basins from about 2 to 70 square miles.

The regression equations were developed using data for streams with a wide variety of basin features. However, additional data collection and testing is necessary to confirm if the equations are applicable for streams in mountainous areas other than the Medicine Bow Mountains and Sierra Madre.

Test of Estimating Methods

Mean monthly flows at the selected sites were determined using a concurrent-measurement method whereby correlation of the discharge measurements is made with daily mean discharges at a nearby streamflow-gaging station (Riggs, 1969; Parrett and Cartier, 1990, and Lowham, 1988, p. 35).

Concurrent-measurement method

The concurrent-measurement method is used to estimate streamflow at selected sites by correlating with concurrent discharges at one or more nearby gaged sites. The flow rate of a small perennial mountain stream generally does not fluctuate much during the winter. Flow rates of similar streams in the same general area are highly correlated because the same basin and climatic features commonly affect them.

- The selected sites should be in the same general area as the gaged site and have drainage basins with hydrologic similarities.
- Streamflows are measured mid-month at each selected site and are correlated with concurrent daily mean flows at the gaged sites.
- The relation between measured streamflows at the two sites is then used to transfer the mean monthly streamflow characteristic at the gaged site to the selected site.

Streamflows fluctuate from year-to-year, depending on the weather. Monthly discharge measurements at the selected sites, therefore, need adjustment to account for dry or wet years. For example, the mean daily flow measured at the gaged site BC-1 was 9.6 cubic feet per second on October 23, 2000. The mean monthly discharge at the gage for water years 1961-2001 is 14.0 cubic feet per second, which is 1.46 times greater than 9.6 cubic feet per second. The measured discharge at each of the selected sites was therefore multiplied by 1.46 to determine the adjusted mean monthly discharge for October.

Adjustment coefficients were determined for each month:

Month 2000-2001	**a** Long-term mean discharge for water years 1961-2001 (ft^3/s)	**b** Mean daily discharge for measurement day (ft^3/s)	**a/b = c** Coefficient for determining adjusted mean monthly discharge (ft^3/s)
Oct.	14.0	9.6	1.46
Nov.	11.5	8.2	1.40
Dec.	10.0	9	1.11
Jan.	9.27	8.4	1.10
Feb.	9.24	7.6	1.22
Mar.	10.5	7.7	1.36
Apr.	23.6	27	0.87
May	169	N/A	N/A
June	258	N/A	N/A
July	56.3	N/A	N/A
Aug	13.8	N/A	N/A
Sept	12.6	N/A	N/A
Annual	**49.9**	N/A	N/A

Similar computations were made for each of the selected sites. Table B-3 (Appendix B) summarizes the adjusted mean monthly flows.

The concurrent-measurement method uses field visits and discharge measurements to determine estimates of mean monthly flow. This method is considered relatively accurate compared with office methods.that use measurements of basin characteristics from maps.

Data from the concurrent-measurement method were used to test mean monthly streamflows estimated from the following methods:

- Two sets of equations using basin characteristics as independent variables for estimating mean monthly flows, developed by Misalis, Wesche, and Lowham (1999, pp. 109, 85);

- Equations using basin characteristics as independent variables, for estimating mean annual flow, with monthly flows estimated on the basis of relative proportion of monthly flow for a nearby streamflow-gaging station (Lowham, 1988, p. 28); and

- Equations using basin characteristics as independent variables, developed for this study.

Equations developed by Misalis and others

Equations developed by Misalis, Wesche, and Lowham (1999) use basin characteristics and channel width to estimate streamflow values. One set of estimating equations used by (Misalis, Wesche, and Lowham; 1999, p. 109) was developed using data for 24 gaged streams in the Medicine Bow Mountains. The equation from this data set for estimating October mean monthly flow using basin characteristics is:

$$Q_{Oct} = 0.77446\ DA^{.729} \quad ,$$

where

Q_{Oct} = mean monthly flow, in cubic feet per second, and

DA = contributing drainage area, in square miles.

A second set of estimating equations (Miselis, Wesche, and Lowham, 1999, p. 85) was developed using data for 130 gaged streams in mountainous regions throughout Wyoming. Equations from this data set for estimating October mean monthly flow using basin characteristics are:

$$Q_{Oct} = 0.40148\ DA^{.907} \quad \text{, and}$$

$$Q_{Oct} = 0.00351\ DA^{.891}p^{1.57} \quad ,$$

where

P = average annual precipitation, in inches.

Mean annual flow equations developed by Lowham

Mean annual flow was estimated using equations developed by Lowham (1988, p. 28). Data for 140 gaged streams in the mountainous regions of Wyoming were used. The equation using basin characteristics for estimating mean annual flow is:

$$Q_a = 0.013\ A^{0.93}PR^{1.43}$$

where

Q_a = mean annual flow, in cubic feet per second,

A = contributing drainage area, in square miles, and

PR = average annual precipitation, in inches.

Using the method described by Lowham (1988, p. 40, 41), the October mean monthly flow at site BC-1 (gaging station 06622700) is 14 cubic feet per second, which is 2.34 percent of the mean annual flow. Using the equation above, the estimated mean annual flow at site BC-4 is:

$$Q_a = 0.013\ A^{0.93}PR^{1.43}$$

$$= 0.013\ (2.77)^{0.93}(25)^{1.43}$$

$$= 3.35 \text{ cubic feet per second.}$$

Mean monthly flows for site BC-4 are then computed using percentages for each month as shown below:

Month	**a** Long-term mean at gaged site BC-1 (station 06622700) for water years 1961-2001 (ft^3/s)	**b** Monthly flow/ annual runoff/ months a/49.9/12(100) (percent)	Mean monthly flow at selected site b × 3.35 × 12 (ft^3/s)
Oct	14.0	2.338009	0.94
Nov	11.5	1.920508	0.77
Dec	10.0	1.670007	0.67
Jan	9.27	1.548096	0.62
Feb	9.24	1.543086	0.62
Mar	10.5	1.753507	0.70
Apr	23.6	3.941216	1.58
May	169	28.223113	11.3
June	258	43.086172	17.3
July	56.3	9.402138	3.78
Aug	13.8	2.304609	0.92
Sept	12.6	2.104208	0.84
Annual	**49.9**	**100**	**3.35**

The studies by Miselis, Wesche, and Lowham (1999) and Lowham (1988) also present equations using channel width to estimate streamflow.

Comparison of estimating methods

The concurrent-measurement method uses discharge data obtained for each month at the site. It therefore is considered to be a relatively accurate means for determining streamflow, outside of operating a long-term gaging station. Estimates of the mean monthly flow were determined using each of the methods described above, including the equations developed as part of this study. These estimates were then compared with the estimates of mean monthly flow that were determined from the concurrent-measurement method.

The results are summarized below, by month and measurement site. Shown is the number of times that each estimating method was closest to the values obtained by the concurrent-measurement method.

	Miselis and others p. 109	Miselis and others p. 85	Lowham, 1988 p. 28	Regression relations developed in this study
Oct.	2	2	4	11
Nov.	2	6	6	14
Dec.	2	9	2	13
Jan.	9	5	4	10
Feb.	7	2	7	13
March	4	2	10	16
Sum	**26**	**26**	**33**	**77**

For example, in October, the Lowham (1988) method was best for 4 of the sites, while the equations developed for this study were closest for 11 sites. Comparisons were made for 28 sites, so, in principle, the row sums should equal this number. But in practice, in October and December data were not available while in other months two or more estimating methods were tied for closest and each was recorded in the table.

The equations developed for this study provide estimates of mean monthly flow that are closest to the mean monthly flows determined by the concurrent discharge method for a relatively large number of cases. Based on this comparison, it appears that an improved set of estimating equations has been developed for determining low flows in the mountains of southeast Wyoming. The new set of equations is based on a large amount of data for small streams with drainage areas smaller than about 70 square miles; whereas the previous methods were based on a set of data that included larger streams. For streams with drainage areas larger than about 70 square miles, either of the previous methods is considered appropriate.

Using Estimating Equations

Example

Estimates of monthly flows are needed for determining water rights for instream fisheries on Sourdough Creek, a tributary of South French Creek in the Medicine Bow Mountains (fig. 7). The contributing drainage area at the upstream end of the stream reach is 1.85 square miles, and the range in elevation is 1,172 feet. The estimated flow for February (Q_{Feb}) using the regression equation based on the area (Area) and range of elevation (RngEl) of the basin is:

$$Q_{Feb} = 0.000149 \text{ Area}^{0.71} \text{ RngEl}^{1.00}$$

$$Q_{Feb} = 0.000149\ (1.85)^{0.71}\ (1{,}172)^{1.00}$$

$$= 0.27 \text{ cubic feet per second}$$

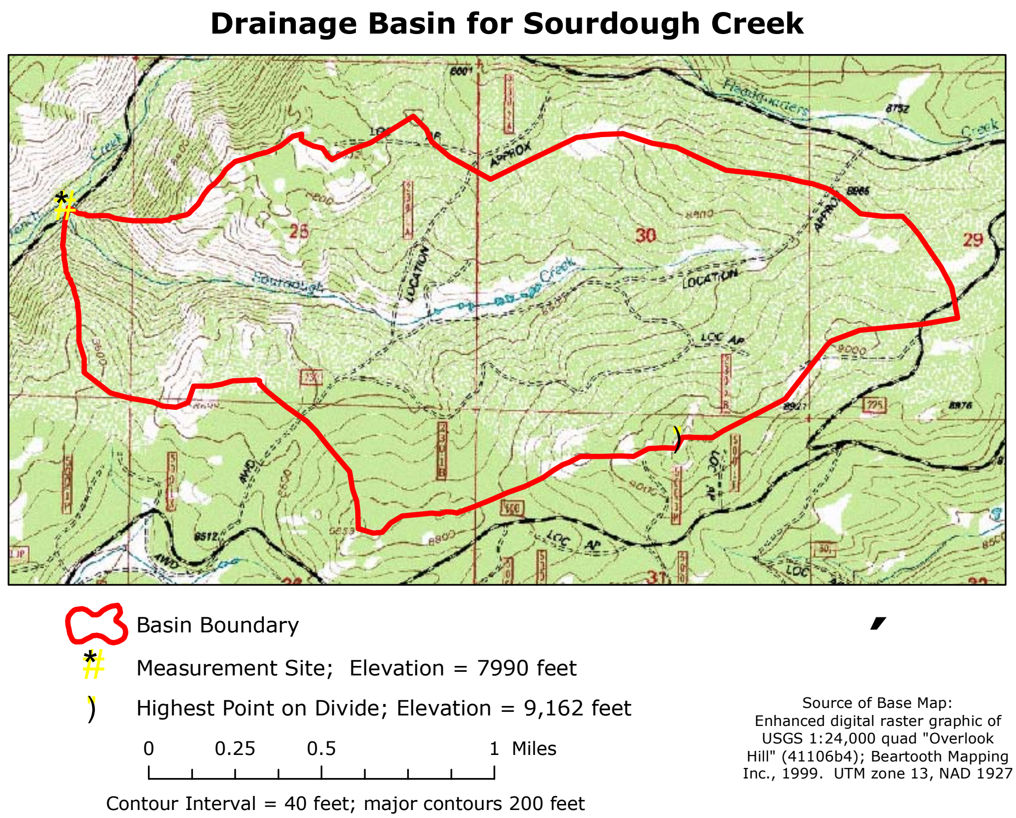

Figure 7. Map of drainage basin for Sourdough Creek.

Study Training

During the first year of the study, technical experience in hydrology and GIS was provided to Justin Montgomery, an undergraduate student. Justin was an active participant in data collection and analysis. He participated in the August 14, 2000 field site visit and compiled digital map files of the study area.

The second year of the study, graduate student James Riley was assigned to the project. During the summer 2001, he worked with Dr. Larry Ostresh to compile a digital database of the study areas. Beginning in the fall 2001, he assisted with developing an analysis to determine the effect of various parameters, such as clearcut areas and snow-water equivalent on base flows. This work continued through the spring 2003.

Mr. Riley completed (May 2003) a Masters Degree from the Department of Geography and Recreation at the University of Wyoming under the direction of Dr. Ostresh. His thesis topic, “Hydrologic modeling of winter streamflow in mountainous areas of Wyoming,” stems directly from his work on this study. In addition to the thesis, Mr. Riley presented two papers related to this study at meetings of professional societies. (See *Volume 2, Supplemental Information, Appendix C*)

Summary

The initial plan for the study was to use sites in the Brush Creek drainage to identify basin characteristics for improving low-flow estimates at ungaged sites. The procedure involved (1) making monthly discharge measurements at selected sites during the winter low-flow months and (2) identifying measurable basin features that cause differences in low flows. The sites selected and measured during the first year of the study had relatively uniform basin characteristics and streamflow yields. During the second year, new sites in three additional drainages were selected to obtain a greater variety of basin features.

Numerous basin characteristics were measured for each of the selected sites. Digital topographic maps, and aerial photographs and imagery were used to quantify physical and climatic variables of the basins. Maps were prepared that showed surface geology, soil cover, land cover, precipitation, areas of wetlands, and areas of forest harvest.

Estimates of mean monthly flows were made using discharge measurements at the selected sites, which were correlated with the flows of nearby long-term streamflow-gaging stations. Streamflow for the selected sites were then related to basin characteristics to develop regression equations for estimating low flows at ungaged sites. Drainage area and range in basin elevation were found to be the most significant and consistent variables for estimating low flows. Several basin measurements, including April snow-water equivalent, area of wetlands and forest harvest showed promising results for individual drainage areas, but not for the drainages as a whole.

References

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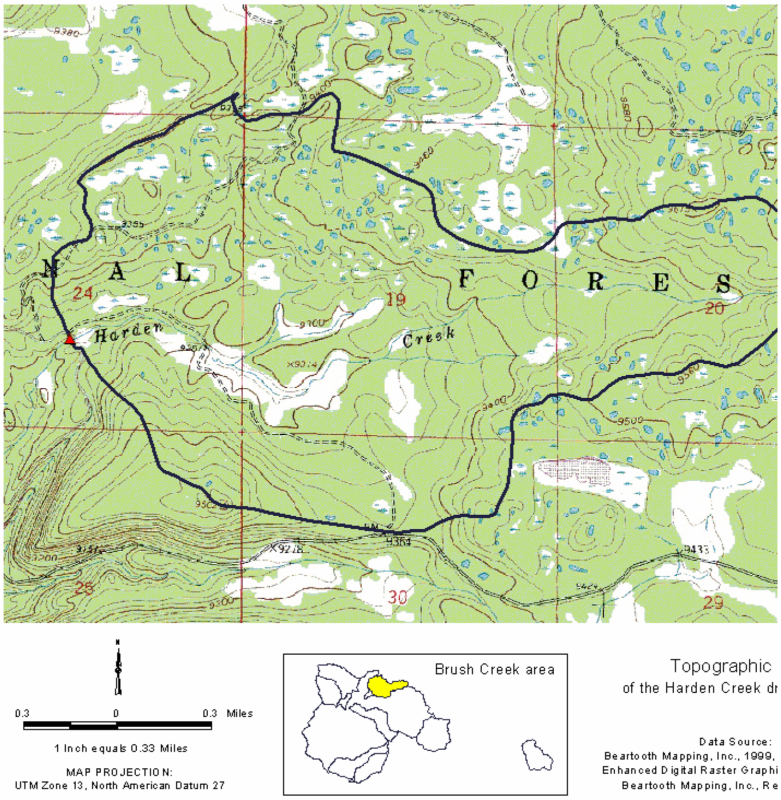
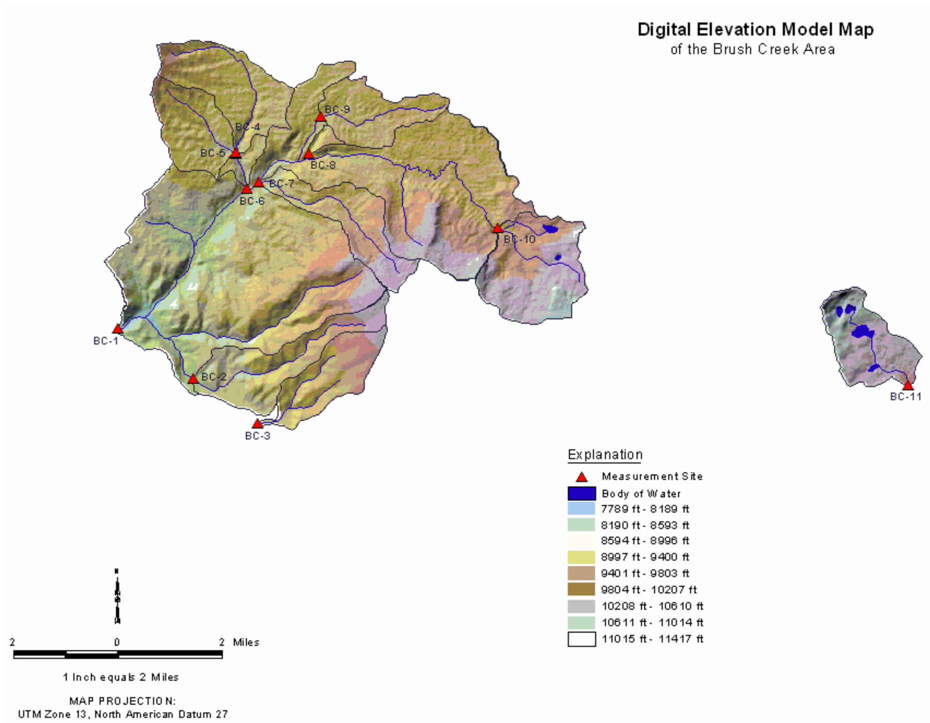
Riley, J.D., 2003, Hydrologic modeling of winter streamflow in mountainous areas of southeast Wyoming. M.A. thesis, Department of Geography and Recreation, University of Wyoming, Laramie, WY.

Riley, J.D., 2003, The use of geographic information systems to model winter low-flow stream discharge in mountainous areas of southeast Wyoming. Paper presentation. 99th Association of American Geographers Annual Meeting, New Orleans, LA.

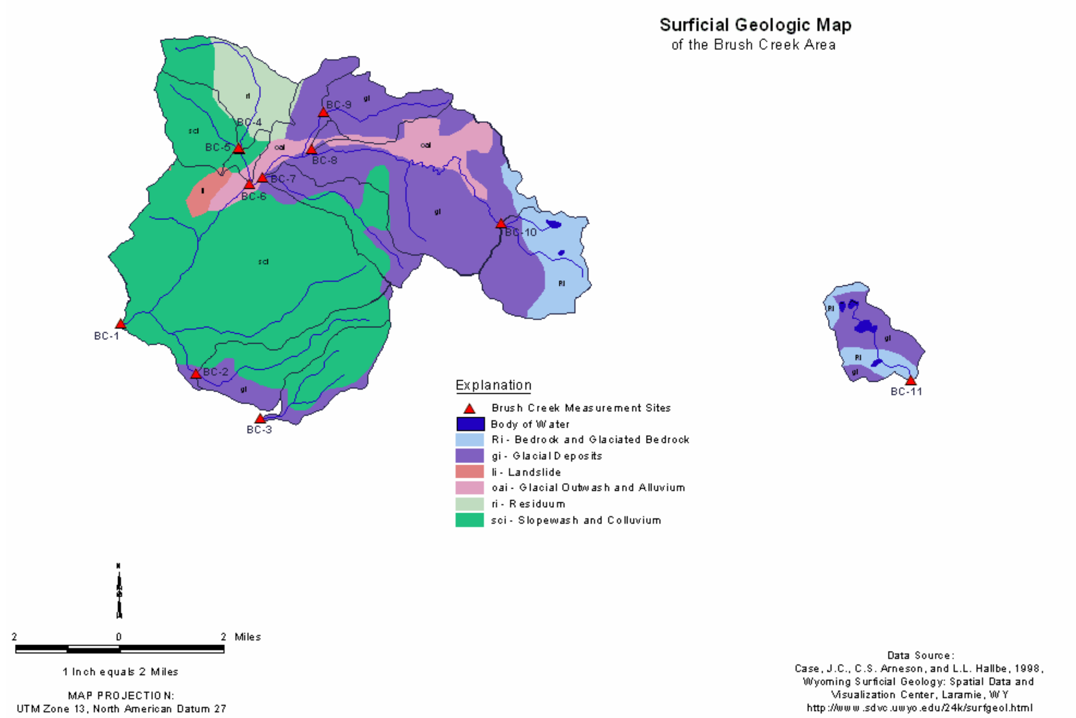
Appendix A – Drainage Basin Maps



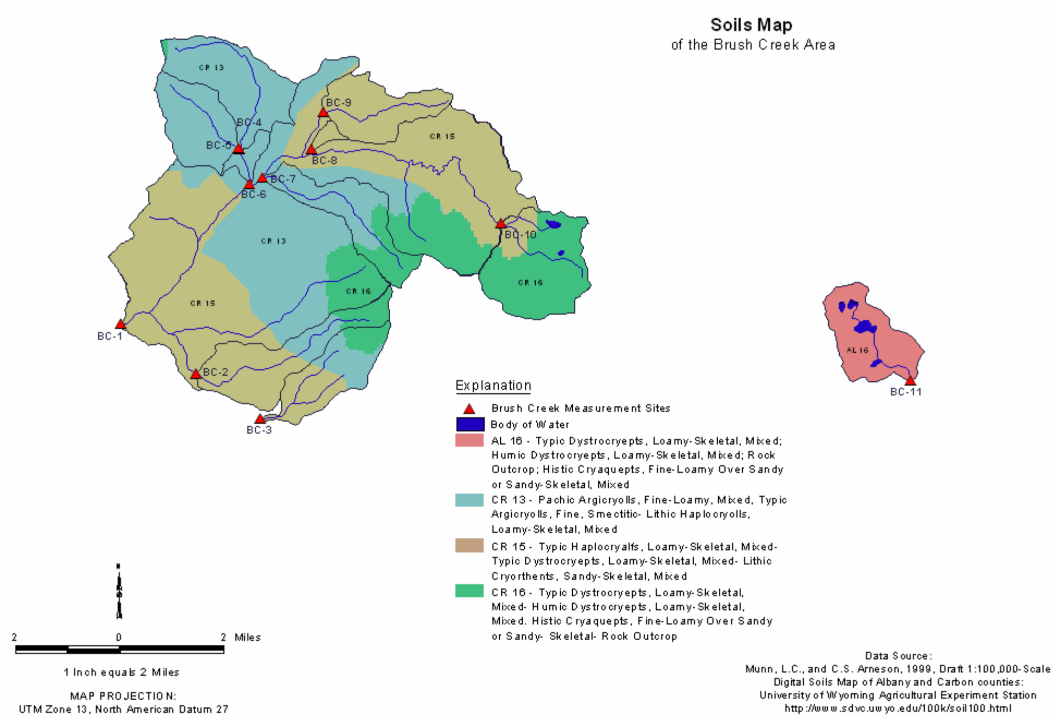
A-1 Topographic map of Harden Creek drainage basin, Brush Creek area.



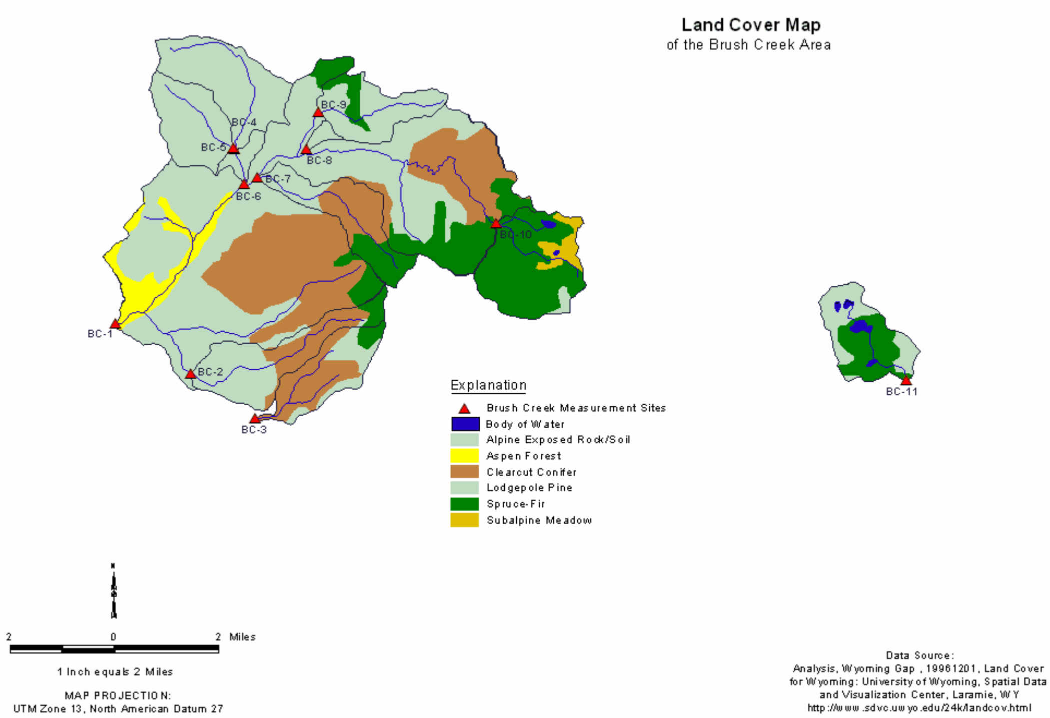
A-2 Digital elevation model map of drainage basins in Brush Creek area.



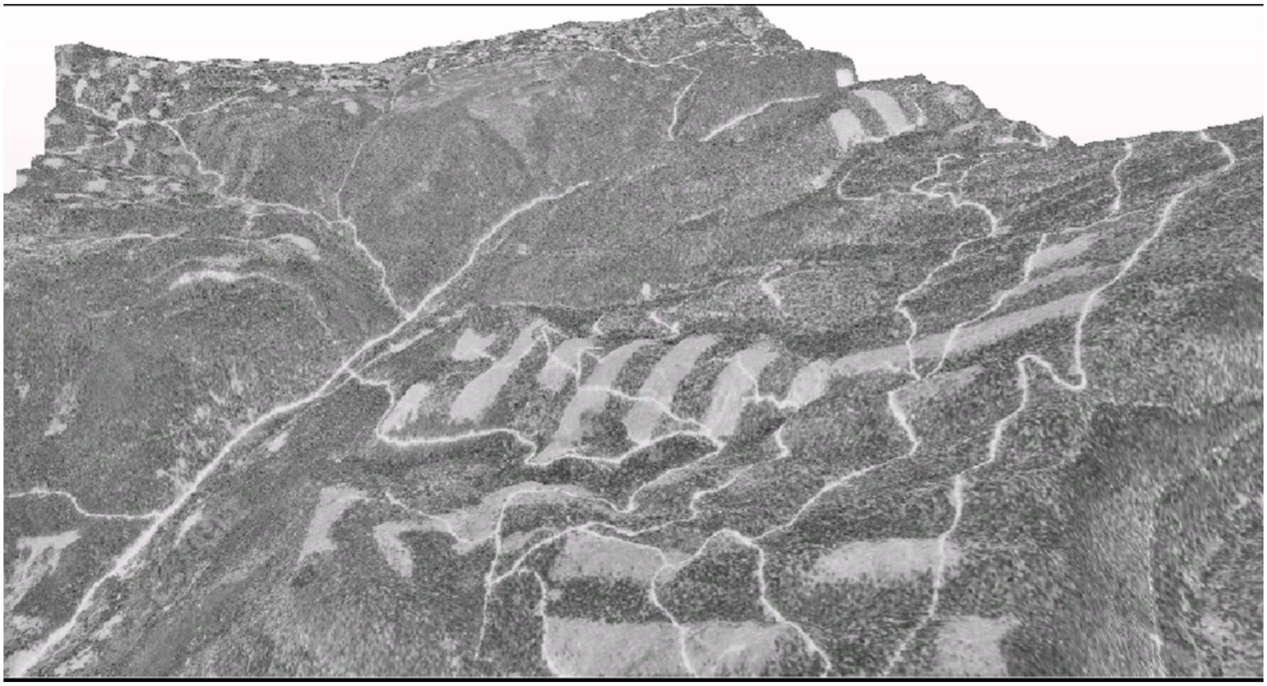
A-3 Surface geology map of drainage basins in Brush Creek area.



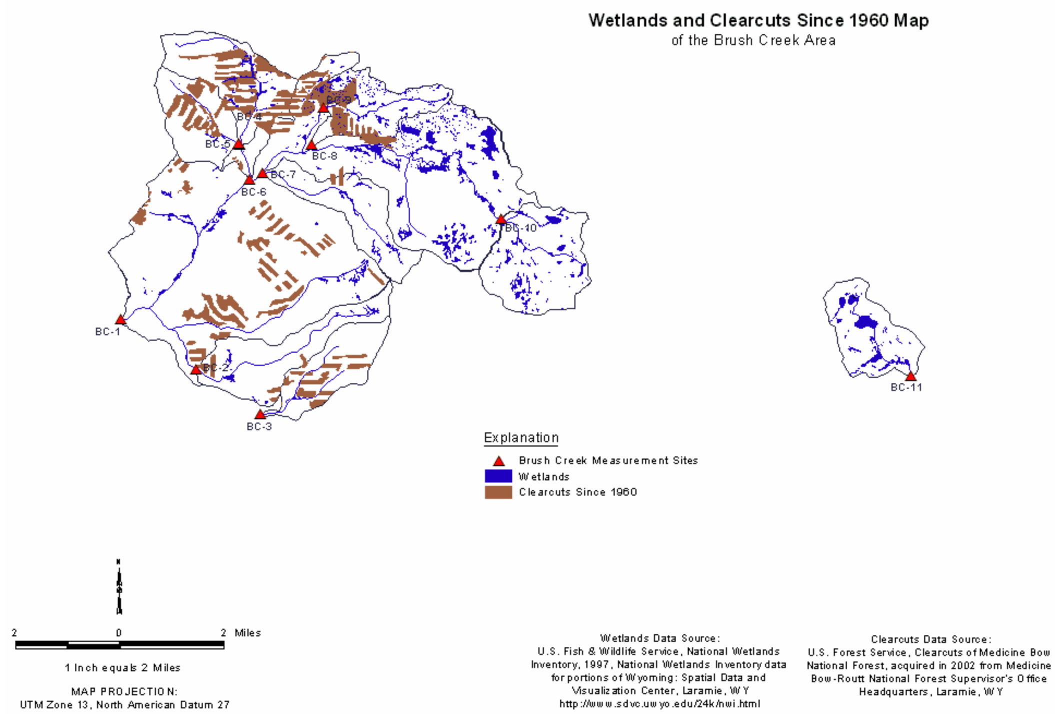
A-4 Soils map of drainage basins in Brush Creek area.



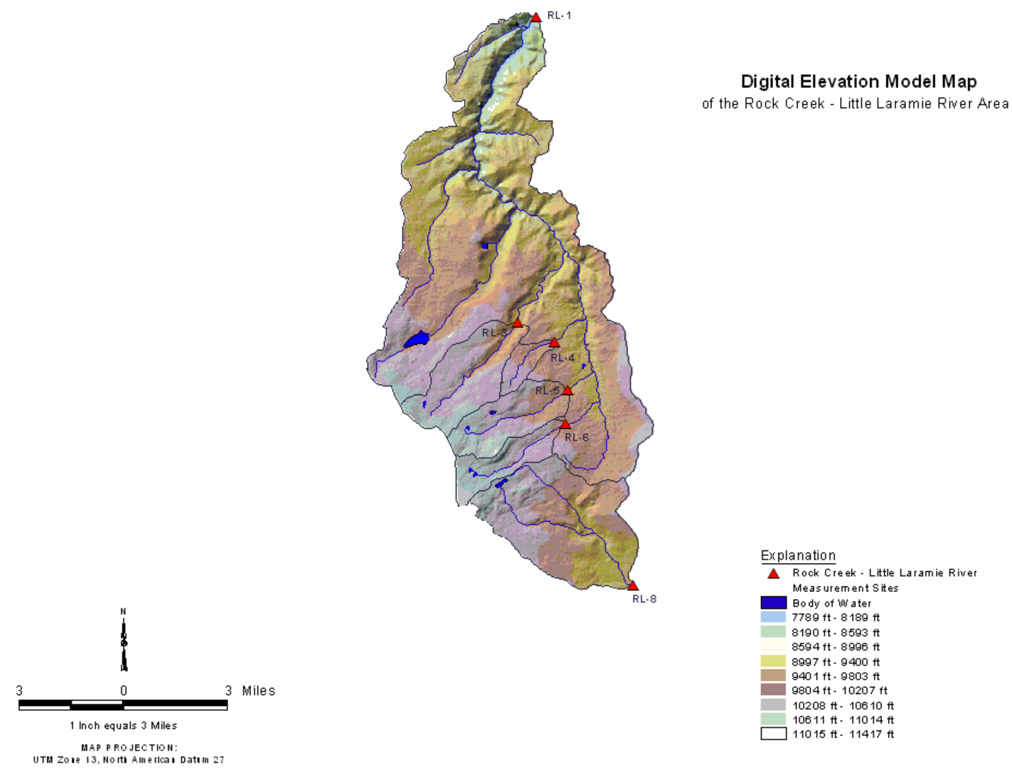
A-5 Land cover map of drainage basins in Brush Creek area.



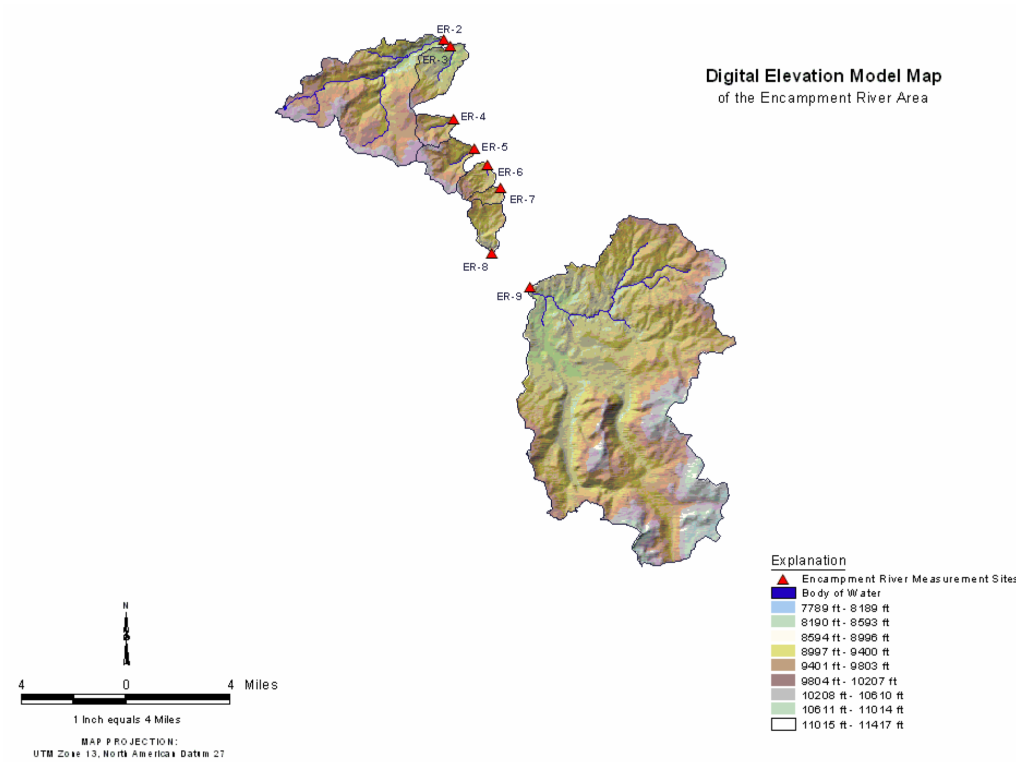
A-6 Aerial photograph of clearcuts in Brush Creek area.



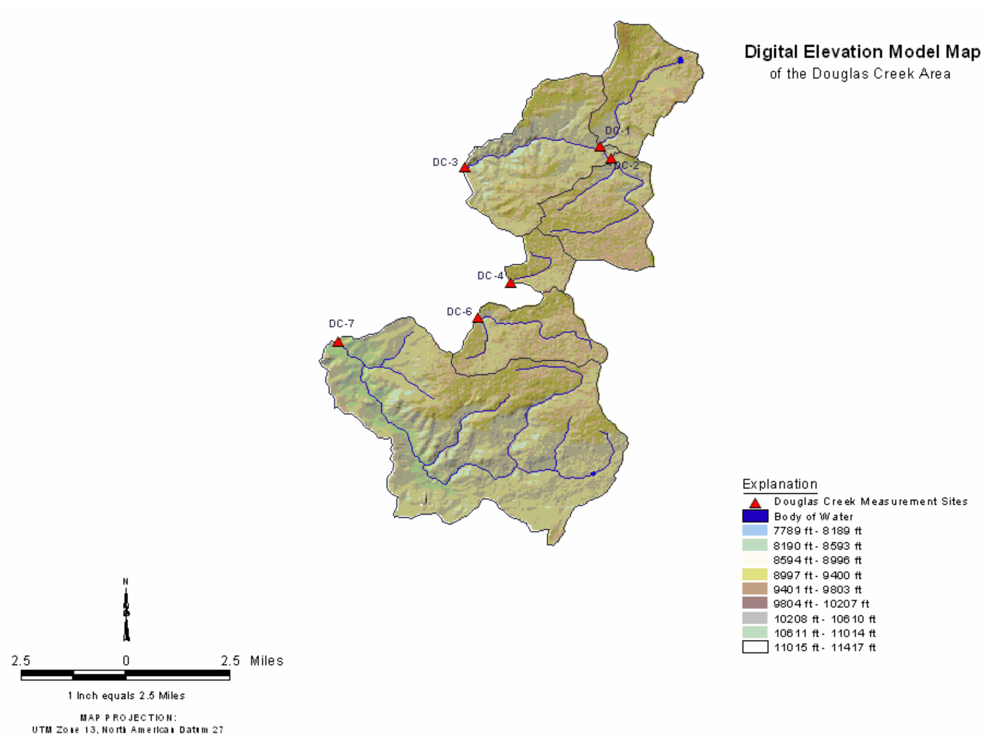
A-7 Clearcuts, group selection, and wetlands in drainage basins.



A-8 Digital elevation model map of drainage basins in Rock Creek— Little Laramie River area.



A-9 Digital elevation model map of drainage basins in Encampment River area.



A-10 Digital elevation model map of drainage basins in Douglas Creek area.

Appendix B – Tables

Table B-1 Summary of streamflow sites and basin characteristics.

Site	Site Name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Area (mi^2)	RngEl (ft)
BC-1	North Brush Creek Gage, 06622700	41 22 09	106 31 22	37.8	2822
BC-2	Lincoln Creek	41 21 20	106 29 41	2.71	2172
BC-3	Mill Creek	41 20 37	106 28 15	2.01	1696
BC-4	Fish Creek, Upper Site	41 25 04	106 28 49	2.77	1470
BC-5	Unnamed Tributary to Fish Creek	42 25 05	106 28 51	1.97	1181
BC-6	Fish Creek, Lower Site	41 24 29	106 28 35	5.13	1667
BC-7	Cassidy Creek	41 24 35	106 28 19	2.24	1880
BC-8	Unnamed Tributary	41 25 05	106 27 14	0.17	453
BC-9	Harden Creek	41 25 42	106 26 58	1.96	407
BC-10	North Brush Creek, Upper Site	41 23 54	106 23 03	3.31	1171
BC-11	Nash Fork Creek, Above Brooklyn Lake Lodge	41 21 25	106 13 57	2.16	1289
RL-1	Rock Creek Gage, 06632400	41 35 09	106 13 17	62.9	3448
RL-3	North Fork Rock Creek	41 27 33	106 13 45	5.56	1240
RL-4	Middle Fork Rock Creek	41 27 05	106 12 30	1.19	814
RL-5	Park Trail Creek	41 25 53	106 12 03	4.26	1358
RL-6	South Fork Rock Creek	41 25 03	106 12 07	2.86	1217
RL-8	North Fork Little Laramie River	41 21 03	106 09 47	11.65	2139
DC-1	Lake Creek at Lincoln Creek	41 07 29	106 10 22	5.03	988
DC-2	Lincoln Creek at Lake Creek	41 07 14	106 10 03	5.24	453
DC-3	Lake Creek at Douglas Creek	41 07 00	106 14 02	18.04	1220
DC-4	Illinois Creek	41 04 36	106 12 45	1.55	446
DC-6	Park Run Creek	41 03 55	106 13 38	4.42	591
DC-7	Pelton Creek	41 03 23	106 17 27	23.06	948
ER-2	North Fork Encampment River	41 09 35	106 53 25	16.24	2375
ER-3	Willow Creek	41 09 23	106 53 06	3.08	1991
ER-4	Miner Creek	41 06 56	106 52 53	1.45	1276
ER-5	South Fork Miner Creek	41 05 59	106 51 57	2.71	1453
ER-6	North Soldier Creek	41 05 27	106 51 21	1.25	1175
ER-7	South Soldier Creek	41 04 41	106 50 50	0.59	912
ER-8	Unnamed Creek	41 02 31	106 51 07	1.76	1588
ER-9	Hog Park Creek Gage, 06623800	41 01 50	106 49 29	72.4	3140

Table B-2 Summary of streamflow measurements.

[Brush Creek (BC) sites were measured during 2000-2001. Rock Creek - Little Laramie River (RL), Douglas Creek (DC), and Encampment River (ER) sites were measured during 2001-2002]

Site	October (ft^3/s)	November (ft^3/s)	December (ft^3/s)	January (ft^3/s)	February (ft^3/s)	March (ft^3/s)
BC-1	10.10	12.50	9.08	9.00	8.00	7.78
BC-2	0.40	0.47	0.49	0.44	0.48	0.46
BC-3	0.14	0.19	0.20	0.19	0.18	0.18
BC-4	0.39	0.71	0.64	0.55	0.62	0.56
BC-5	0.41	0.39	0.56	0.27	0.37	0.38
BC-6	0.78	1.03	-	0.96	0.67	0.90
BC-7	1.08	0.88	0.82	0.81	0.80	0.76
BC-8	0.00	0.00	0.00	0.00	0.00	0.00
BC-9	0.22	0.20	0.31	0.38	0.46	0.34
BC-10	0.35	-	-	-	-	-
BC-11	-	0.58	-	0.42	0.38	0.52
RL-1	-	-	-	-	-	-
RL-3	0.67	0.65	0.39	0.13	0.35	0.32
RL-4	0.07	0.10	0.07	0.07	0.07	0.06
RL-5	0.75	0.76	0.39	0.32	0.24	0.24
RL-6	0.20	0.26	0.09	0.04	0.08	0.08
RL-8	2.63	2.36	1.82	1.53	1.49	1.60
DC-1	0.68	0.34	0.28	0.29	0.42	0.34
DC-2	0.22	0.27	0.19	0.24	0.25	0.32
DC-3	0.85	1.19	1.49	0.71	1.15	1.80
DC-4	0.03	0.03	0.04	0.04	0.03	0.03
DC-6	-	0.08	0.06	0.07	0.07	0.12
DC-7	0.87	0.97	0.77	1.09	0.85	0.83
ER-2	-	1.96	1.69	2.11	1.48	1.42
ER-3	-	0.57	0.37	0.72	0.50	0.31
ER-4	-	0.26	0.24	0.23	0.20	0.21
ER-5	-	0.45	0.47	0.35	0.36	0.29
ER-6	-	0.30	0.32	0.28	0.19	0.18
ER-7	-	0.12	0.12	0.10	0.08	0.08
ER-8	-	0.38	0.34	0.30	0.30	0.35
ER-9	-	17.60	-	15.20	-	-

Table B-3. Summary of adjusted mean monthly flows.

[Brush Creek (BC) sites were measured during 2000-2001. Rock Creek - Little Laramie River (RL), Douglas Creek (DC), and Encampment River (ER) sites were measured during 2001-2002]

Site	October (ft^3/s)	November (ft^3/s)	December (ft^3/s)	January (ft^3/s)	February (ft^3/s)	March (ft^3/s)
BC-1	14.00	11.50	10.00	9.27	9.24	10.50
BC-2	0.58	0.66	0.54	0.48	0.59	0.63
BC-3	0.20	0.27	0.22	0.21	0.22	0.24
BC-4	0.57	0.99	0.71	0.61	0.76	0.76
BC-5	0.60	0.55	0.62	0.30	0.45	0.51
BC-6	1.14	1.44	-	1.06	0.82	1.22
BC-7	1.58	1.23	0.91	0.89	0.98	1.03
BC-8	0.00	0.00	0.00	0.00	0.00	0.00
BC-9	0.32	0.28	0.34	0.42	0.56	0.47
BC-10	0.51	-	-	-	-	-
BC-11	-	0.81	-	0.46	0.46	0.71
RL-1	16.90	13.80	11.80	10.80	10.40	10.60
RL-3	1.13	0.81	0.46	0.16	0.53	0.50
RL-4	0.12	0.12	0.09	0.09	0.10	0.10
RL-5	1.27	0.95	0.46	0.40	0.36	0.37
RL-6	0.33	0.33	0.11	0.05	0.12	0.12
RL-8	4.44	2.95	2.15	1.90	2.28	2.50
DC-1	0.96	0.41	0.38	0.38	0.54	0.48
DC-2	0.32	0.32	0.26	0.31	0.33	0.45
DC-3	1.20	1.42	2.01	0.92	1.51	2.59
DC-4	0.03	0.04	0.05	0.06	0.04	0.05
DC-6	-	0.10	0.08	0.09	0.09	0.17
DC-7	1.23	1.15	1.03	1.42	1.11	1.20
ER-2	-	2.72	2.23	2.81	2.00	1.78
ER-3	-	0.79	0.49	0.96	0.67	0.38
ER-4	-	0.35	0.32	0.30	0.27	0.26
ER-5	-	0.63	0.62	0.46	0.49	0.36
ER-6	-	0.42	0.42	0.37	0.25	0.23
ER-7	-	0.16	0.15	0.14	0.11	0.10
ER-8	-	0.53	0.44	0.40	0.40	0.43
ER-9	-	25.10	22.50	20.00	18.90	20.00